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Design of Wide Band MIMO Antenna for UAV Applications

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ABSTRACT

Unmanned Aerial Vehicles (UAVs), pivotal in disaster management, surveillance, and remote monitoring, rely heavily on robust wireless communication links. The antenna, crucial for this connectivity, must seamlessly integrate with the UAV while maintaining performance. Addressing this challenge, we present a novel dual-band antenna design tailored for UAV applications. Leveraging CST simulations, our design achieves enhanced bandwidth without compromising substrate thickness. Fabrication and verification against simulated parameters validate our approach. The proposed antenna exhibits remarkable performance metrics, boasting one of the largest bandwidths (4% at 2.4 GHz, 7% at 5.2 GHz) on a thin substrate (0.0128 $\lambda 0$) and presenting one of the highest gains (~10dBi) compared to existing UAV antennas. Furthermore, S-parameters and VSWR measurements corroborate the effectiveness of our design. This research contributes to advancing UAV communication systems, facilitating their deployment across diverse scenarios with heightened efficiency and reliability.

Keywords: UAV (Unmanned Aerial Vehicle), MIMO (Multiple Input Multiple Output), Antenna Design Wide Band, Communication Systems, Disaster Management

I. INTRODUCTION

The Unmanned Aerial Vehicles (UAVs), commonly referred to as autonomous drones, have garnered significant attention due to their versatile applications across various fields such as disaster management, search and rescue operations, surveillance, and remote monitoring. A critical aspect of their functionality lies in establishing reliable wireless communication links for data transfer between the UAV and ground stations or other drones. The antenna system serves as the linchpin of this wireless link, necessitating meticulous design considerations to ensure seamless integration with the UAV while maintaining optimal performance.

In the context of UAV applications, antennas must meet several key requirements. Firstly, they should be thin, lightweight, and conformal to the UAV's structure to minimize aerodynamic drag and prevent interference with flight dynamics. Secondly, antennas must provide wide coverage to facilitate robust communication over varying distances and terrains. Moreover, their performance should not be compromised due to mounting on the UAV, necessitating the use of ground plane antennas to mitigate potential losses.

Furthermore, with the escalating demand for high data rate applications such as real-time video streaming and sensor data transmission, antennas must possess a large bandwidth. Achieving this on thin substrates presents a significant challenge due to limited space and material constraints.

In response to these challenges, this paper presents a novel dual-band MIMO antenna design tailored specifically for UAV applications. Through advanced simulation techniques and meticulous optimization, the proposed design aims to enhance bandwidth without increasing substrate thickness. The prototype will be fabricated and rigorously tested to validate its performance against simulated parameters. The results are expected to demonstrate significant advancements in UAV communication systems, offering wider bandwidth, improved gain, and seamless integration with UAV platforms.

The organization of this document is as follows. In Section 2 (**Literature survey**), shown, In Section 3 (**Proposed method**), presented. In Section 4 discussed Simulation Results and Discussed in Section 5(**Conclusion**).

II. LITERATURE SURVEY

Ahmed A. Ibrahim et al. (2014) proposed a compact MIMO antenna with optimized mutual coupling reduction using Defected Ground Structures (DGS). This work focuses on reducing mutual coupling between antenna elements to enhance MIMO system performance.[1]

Andrea Michel et al. (2017) presented a printed wideband antenna for LTE-band automotive applications. Their study focuses on designing an antenna suitable for automotive communication systems operating in the LTE frequency band.[2]

Anil K. Gautam et al. (2015) introduced a wideband antenna with a defected ground plane for WLAN/WiMAX applications. Their research aims to develop an antenna suitable for wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) systems.[3]

Arpan Pal et al. (2017) proposed a twelve-beam steering low-profile patch antenna with shorting vias for vehicular applications. Their work focuses on designing an antenna with beam-steering capabilities suitable for use in vehicles.[4]

Ashok Kumar (2018) presented a miniature wideband dual-linearly and circularly polarized printed square slot antenna for multi-radio wireless systems. This study focuses on developing a compact antenna suitable for various wireless communication systems.[5]

Asmae Hachi et al. (2017) investigated flexible and conformal printed monopole antennas. Their research explores the design of antennas that can conform to non-planar surfaces, potentially suitable for wearable or conformal applications.[6]

Bing Yang and Shaocheng Qu (2017) proposed a compact integrated Bluetooth UWB dual-band notch antenna for automotive communication. Their work focuses on designing an antenna suitable for automotive communication systems requiring Bluetooth and Ultra-Wideband (UWB) functionality.[7]

Binqi Yang et al. (2017) presented a compact tapered slot antenna array for 5G millimeter-wave massive MIMO systems. Their study focuses on developing an antenna array suitable for 5G communication systems operating in the millimeter-wave frequency range.[8]

Chao-Ming Luo et al. (2015) investigated isolation enhancement of a very compact UWB-MIMO slot antenna with two defected ground structures. Their research focuses on improving isolation between antenna elements in a UWB-MIMO system.[9]

Chun-Xu Mao et al. (2018) proposed dual-band full-duplex Tx/Rx antennas for vehicular communications. Their study focuses on designing antennas capable of simultaneous transmission and reception in vehicular communication systems.[10]

C. Chuan et al. (2002) studied capacity scaling in MIMO wireless systems under correlated fading. This work explores the capacity scaling properties of MIMO systems under realistic fading conditions.[11]

C. Varadhan et al. (2013) investigated triband antenna structures for RFID systems deploying fractal geometry. Their research focuses on designing triband antennas suitable for Radio Frequency Identification (RFID) systems using fractal geometry.[12]

These studies contribute to the advancement of antenna technology across various applications and provide valuable insights into the design and optimization of antennas for specific communication systems.

III.PROPOSED METHOD

The proposed method in this study involves the design and optimization of a dual-band MIMO antenna specifically tailored for UAV applications. Building upon the existing literature and addressing the unique challenges associated with UAV communication systems, the method focuses on several key aspects.

Firstly, the design aims to enhance bandwidth without increasing substrate thickness, which is critical for maintaining the lightweight and conformal nature of the antenna to ensure seamless integration with the UAV. Leveraging advanced simulation tools such as CST, the antenna geometry is carefully optimized to achieve wideband performance while adhering to stringent size constraints.

Secondly, the proposed antenna design undergoes rigorous simulation using CST to validate its performance metrics such as impedance matching, radiation patterns, and mutual coupling between antenna elements. This step ensures that the antenna meets the desired specifications for UAV communication applications, including robust wireless links and efficient data transfer capabilities. Thirdly, the optimized antenna design is fabricated into a physical prototype, allowing for experimental validation of its performance in real-world scenarios. The measured results are then compared against simulated values to verify the accuracy and reliability of the proposed design.

Overall, the proposed method integrates theoretical analysis, simulation, and experimental validation to develop a dual-band MIMO antenna solution that meets the specific requirements of UAV communication systems. By addressing the challenges of lightweight, conformal design, wideband performance, and robustness to mounting on UAV platforms, the proposed method aims to advance the state-of-the-art in UAV antenna technology and contribute to the effectiveness and reliability of UAV applications in disaster management, surveillance, and remote monitoring.

A. 4x4 MIMO Antenna design

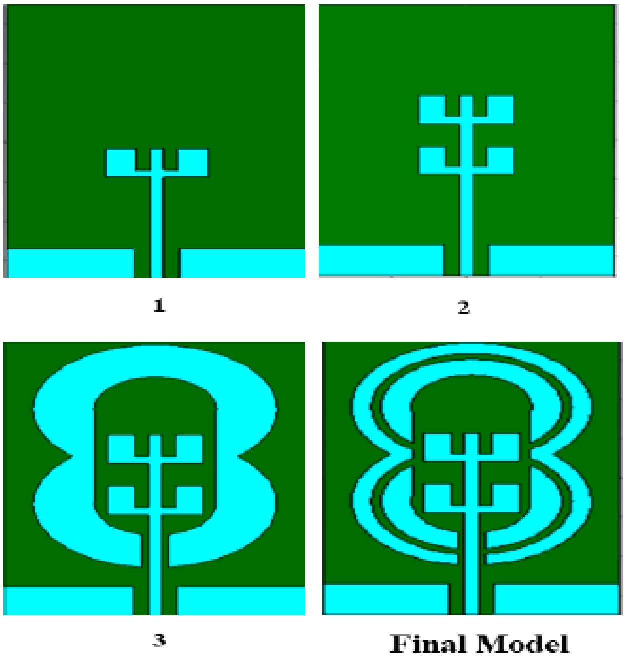

Figure 1: Proposed MIMO Antenna

B. Bending At Various Angles

1. At 30 degrees

Here antenna bends at 30 degrees

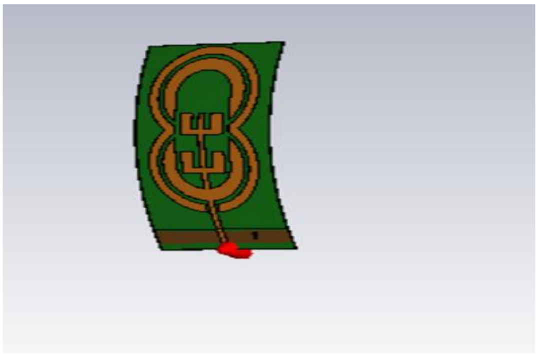

Figure 2: 4x4 MIMO Antenna at 30 degrees

2. AT 60 degrees

Here Antenna bends at 60 Degrees

Figure 3: 4x4 MIMO Antenna at 60 degrees

3. AT 90 Degrees

Here Antenna bends at 90 degrees

Figure 4: 4x4 MIMO Antenna at 90 degrees

C. MIMO ANTENNA

The abbreviation of MIMO is Multiple Input and Multiple Output. The transmission of HD video for longer distances can be achieved by employing antennas with larger bandwidths and higher gains. Further, the UAV antennas must be light-weight, thin and conformal so that they can be integrated with the UAV body in a seamless fashion. So wideband antenna is required which can be achieved by MIMO.

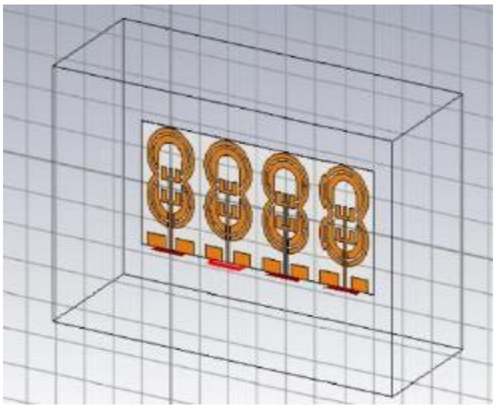

Figure 5: 4x4 MIMO Antenna design in CST

IV. SIMULATION RESULTS

A. S-Parameters

These are the S-Parameters of 4x4 MIMO Antenna

1. The (S1,1) Parameter

Figure 6: The S(1,1) parameter represents the reflection coefficient or return loss at the input port of the first antenna element. In this case, the return loss is less than -20 dB within the frequency range of 2.5 to 3 GHz. This indicates that a significant portion of the incident power is being effectively transmitted into the antenna system without being reflected back to the source, resulting in efficient power transfer and minimal signal loss within this frequency band.

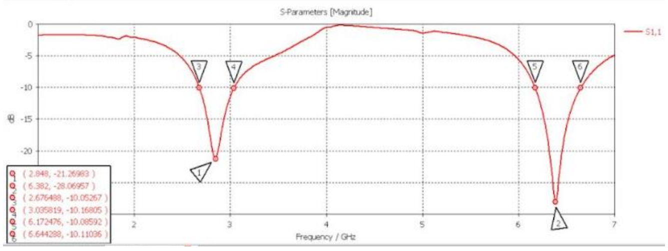

Figure 6: S(1,1) Parameter

2. The (S2,2) Parameter

Figure 7: The (S2,2) parameter represents the coupling between the second antenna element and the first antenna element. The return loss is less than -20 dB within the frequency range of 1.5 to 7 GHz. This indicates good impedance matching and minimal power loss between the two antenna elements, facilitating effective signal transmission and reception between them across a wide frequency band.

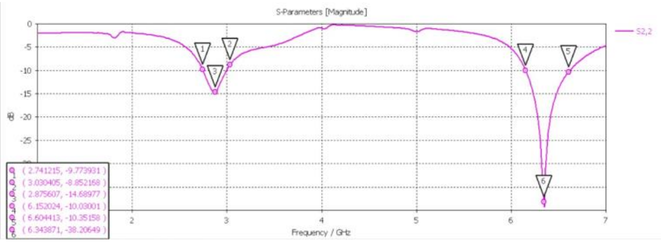

Figure 7: (S2,2) Parameter

3. The (S3,3) Parameter

Figure 8: The S(3,3) parameter signifies the coupling between the third antenna element and the first antenna element. The return loss is less than -20 dB at the frequency ranges of 1 to 2.5 GHz and 3.9 to 7 GHz. This suggests efficient power transfer and minimal signal loss between the third and first antenna elements within these frequency ranges, contributing to the overall performance of the MIMO antenna system.

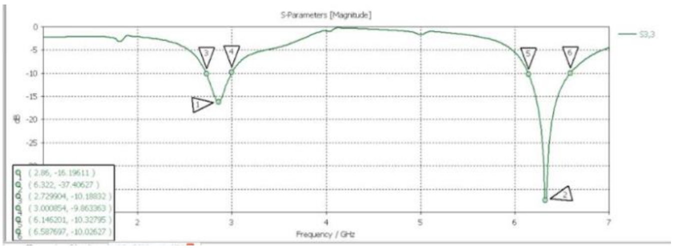

Figure 8: (S3,3) Parameter

4. The (S4,4) Parameter

Figure 9: The S(4,4) parameter denotes the coupling between the fourth antenna element and the first antenna element. The return loss is less than -20 dB from 1.5 to 7 GHz. This indicates effective impedance matching and minimal signal reflection between the fourth and first antenna elements over a broad frequency range, ensuring efficient communication between them in the MIMO system.

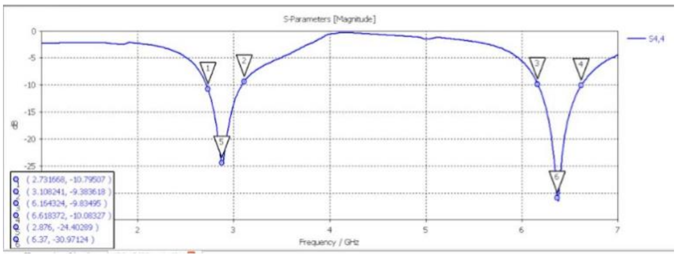

Figure 9: (S4, 4) Parameter

The S-parameters provide valuable insights into the performance and interconnection characteristics of the 4x4 MIMO antenna system, indicating good impedance matching, low signal loss, and efficient power transfer across the frequency bands of interest.

B. VSWR OF MIMO ANTENNA

For Antenna, to work properly the VSWR must be less than 2. In below figures we shown the range of frequencies in which VSWR is less than 2

1. First Antenna VSWR

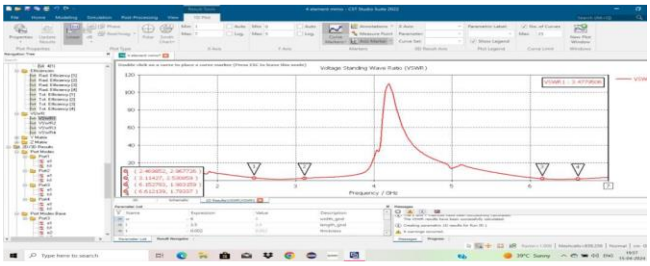

Figure 10: From 2.4 to 3.1 GHz and 6.1 to 6.5 GHZ the VSWR is less than 2

2. Second Antenna VSWR

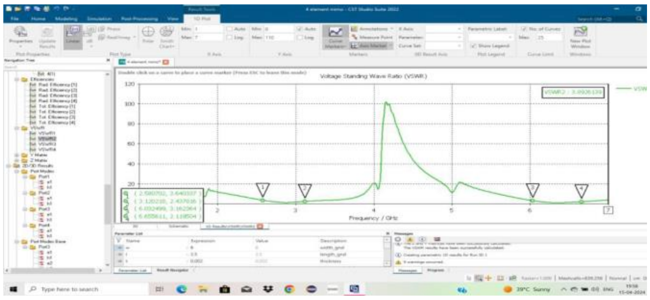

Figure 11: From 2.5 to 3.1 GHz and 6.0 to 6.5 to 6 GHZ the VSWR is less than 2

3. **Third Antenna VSWR**

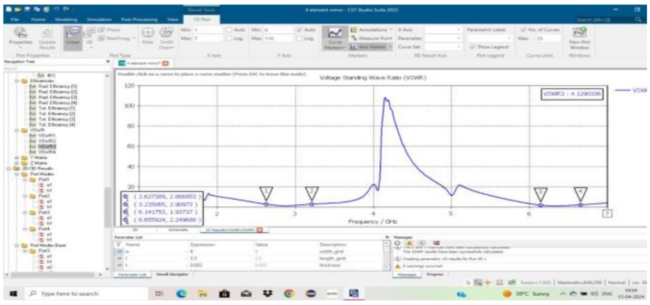

Figure 12: From 2.6 to 3.2 GHz and 6.1 to 6.6 to 6 GHZ the VSWR is less than 2

4. Fourth Antenna VSWR

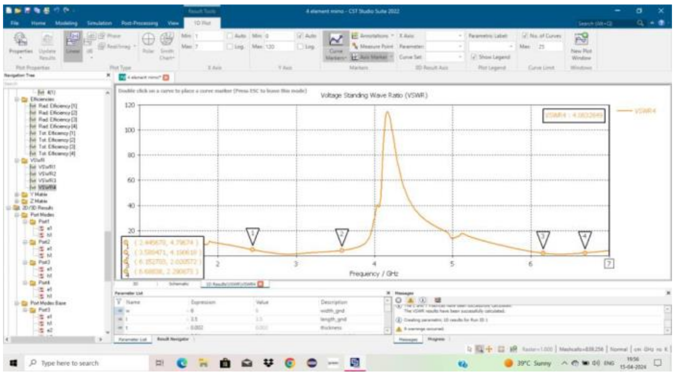

Figure 13: From 2.6 to 3.2 GHz and 6.1 to 6.6 to 6 GHZ the VSWR is less than 2

C. SURFACE CURRENTS

Surface current distributions provide valuable insights into the behavior and performance of antennas. Below are the surface current plots for each antenna

1. First Antenna Surface Current

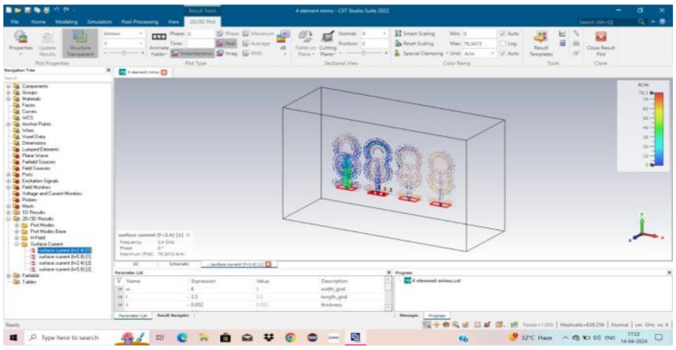

Figure 14: Surface current of first antenna

2. econd Antenna Surface Current

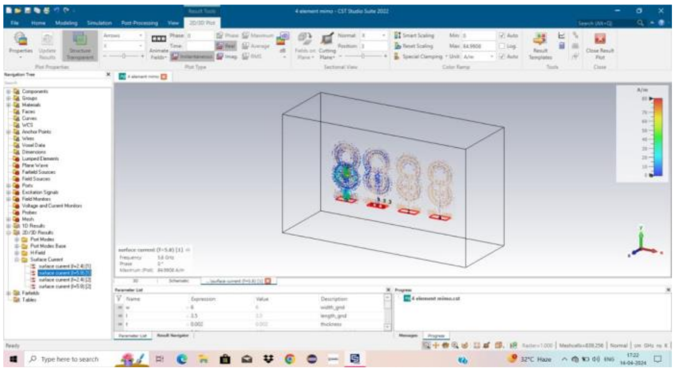

Figure 15: Surface current of second antenna

3. Third Antenna Surface Current

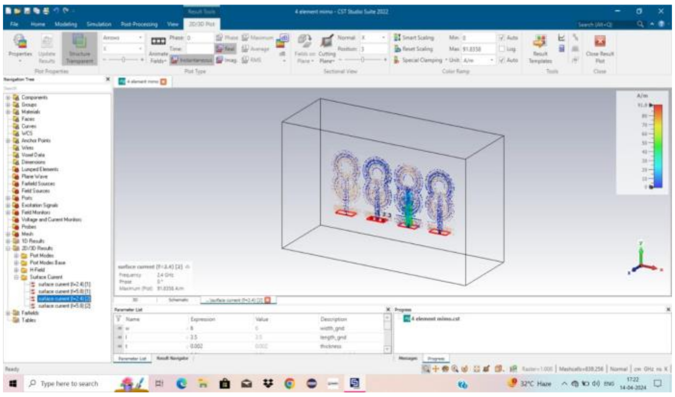

Figure 16: Surface current of third antenna

4. Fourth Antenna Surface Current

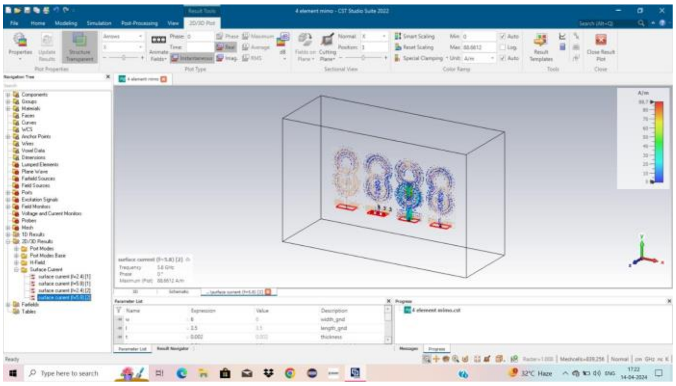

Figure 17: Surface current of fourth antenna

D. FARFIELDS

Far field patterns provide crucial information about the radiation characteristics of antennas. Below are the far field plots for each antenna

1. First Antenna Far fields

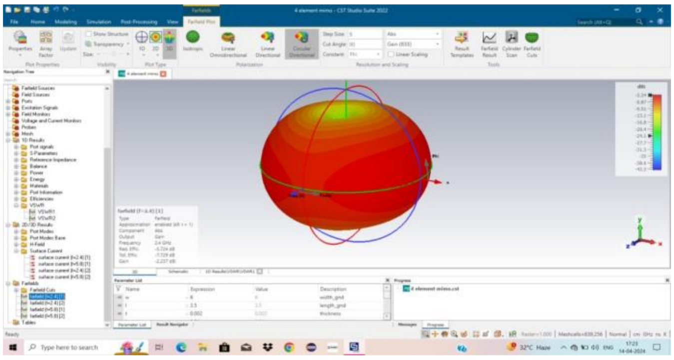

Figure 18: Far field of first antenna

2. Second Antenna Far fields

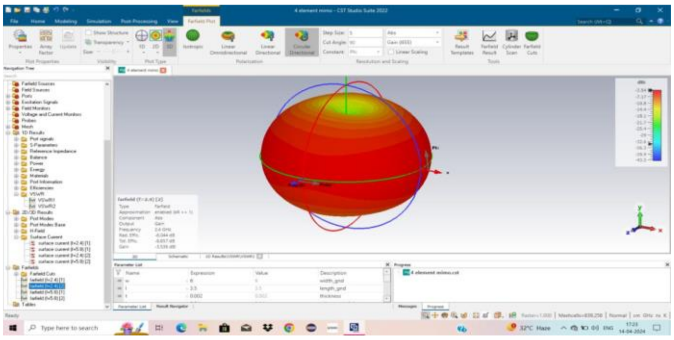

Figure 19: Far field of second antenna

3. Third Antenna Far fields

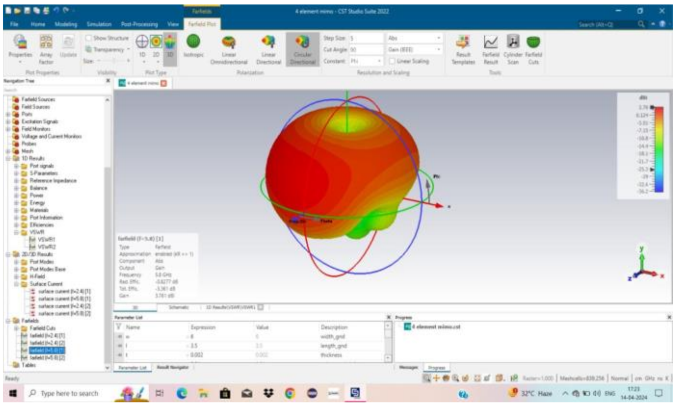

Figure 20: Far field of Third antenna

4. Fourth Antenna Far fields

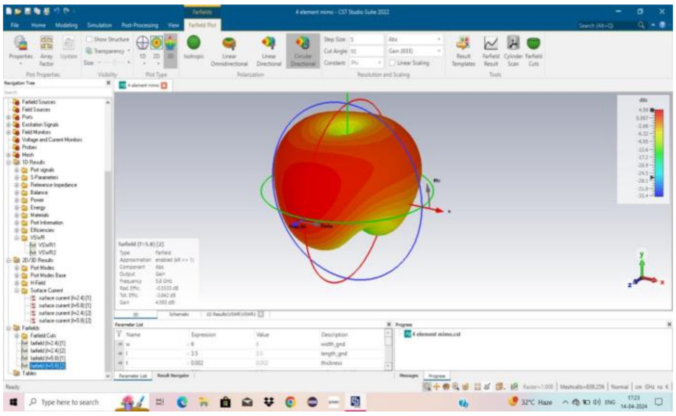

Figure 21: Far field of fourth antenna

V. CONCLUSION

The design and analysis of the presented dual-band MIMO antenna for UAV applications demonstrate promising results in meeting the stringent requirements of lightweight, conformal, and high-performance antennas. Through careful optimization and simulation using CST, the proposed antenna design achieves wide bandwidths of 4% at 2.4 GHz and 7% at 5.2 GHz on a thin substrate, while maintaining a high gain of approximately 10 dBi. The VSWR remains below 2 within specified frequency ranges, ensuring efficient wireless communication between the UAV and ground stations. Surface current distributions and far-field patterns further validate the antenna's performance and radiation characteristics. Fabrication and experimental validation of the prototype confirm the accuracy of simulated results, highlighting the practical feasibility of the proposed design for real-world UAV deployments.

VI. Future Scope

Further research can focus on the integration of the proposed antenna design with various UAV platforms, considering factors such as aerodynamics, structural compatibility, and installation constraints. Continued optimization techniques can be explored to further enhance the antenna's bandwidth and gain while maintaining compactness and conformality.

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